HUBBART

Causes of Defects & Deteriorations In Asphalt Pavements

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CAUSES OF DEFECTS AND DETERIORATIONS IN ASPHALT PAVEMENTS

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Causes of Defects and Deteriorations in Asphalt Pavements.

Introduction.

The object of this thesis is to describe the nature of asphalt pavements, to note the principal causes of the defects and deteriorations that occur within them, and to state, for such imperfections, some remedies, that are recommended by those who are authorities upon the use of asphalt for paving purposes.

Before a description of the nature of an asphalt pavement is given, it will be well to state some facts pertaining to the early development of this method of road construction. The asphalt paving industry has been subjected to many unfortunate abuses through the ignorance and incompetency of those who first attempted to use, by modern methods, natural bitumen in the improvement of public thoroughfares. Until lately the attitude of most engineers was not favorable to a healthy and successful growth. They were not well acquainted with the technology of the industry, and were not able to distinguish between a good and bad pavement either before or after completion. The engineers had not had enough practical experience to realize the true value of chemical analyses of the asphalts; or to have good judgment in the choice of materials or of the methods of handling them. No adequate inspection was provided for. For these reasons they were unable to draw up specifications and guarantee clauses that would compel the contracting company to construct

a pavement that would stand the wear and tear of traffic throughout its average life. In fact until very recently, before the open, standard specifications were adopted by the leading cities of the United States, it was the custom of the municipalities to depend entirely upon time guarantees for good and durable constructions of pavements. When pavements failed and when attempts were made to locate the causes, the official records, so useful in cases like these, were lacking, and the real or probable destructive agents could not be determined. No enlightenment on the subject could be secured from the supply companies, because the Trinidad Asphalt Company controlled the industry commercially, and chose to keep their methods secret.

On account of the conditions memtioned, the development of this industry has been based entirely upon practical experience. No methods, so far, have produced results of such excellent nature, as to be declared standard. Therefore, in this thesis will be described, in detail, the most approved form of construction of sheet asphalt pavements, the defects occurring within them, and the resulting deteriorations.

Composition and Construction of the Pavement.

The completed pavement consists of (a) a foundation of hydraulic concrete, macadam, or some other firm and unyielding material; (b) an intermediate binder course of a mixture of crushed rock, limestone dust and asphaltic cement; and, (c) a top wearing coat of sand and asphaltic cement. Each course varies in thickness for different conditions of traffic, and for different local environments. The materials, classified by percentages of the whole, comprising a sheet asphalt pavement of the usual construction are enumerated in Table I. This pavement consists of a six inch concrete base, a one and one half inch binder course, and a two inch asphalt wearing coat.

Table I.

Materials Expressed by Percentages of the Whole Comprising a Sheet Asphalt Pavement.[1]

Materials	Per cents
Stone (Crushed rock)	52.1
Cement	6.3
Stone dust	3.3
Asphalt.	3.3
Oils	0.6
Sand..	34.4
Total, ...	100.0

1. Asphalt Pavements, by Andrew Rosewater in "Good Road Magazine", 1905.

From this table, it can be seen that 86-1/2 per cent of the completed pavement is composed of a mineral aggregate whose purpose is to bear up the weight and withstand the wear and tear of traffic. The remaining 13-1/2 per cent is composed of the different cementing materials and their accessories. These, in the respective courses in which they are used, serve to bind the hard materials into a solid and impervious mass.

The opinion of many writers is that fifty percent of the failures are due to the insufficient rigidity and thickness of the base, the resulting conditions thus giving a possibility for disintegration by the elements. In order to avoid to a maximum degree any possibility of capillary action of water in the foundation, a complete investigation of the subsoil should be made, and the utmost care should be observed in its proper preparation. First, good drainage must be provided for; second, the surface should be rolled by heavy road rollers until a most compact and impervious surface is secured. Great care must be taken when the adjacent property is of a higher elevation than that of the street, and the bed of the street serves as a natural course for sub-drainage, or when the subfoundation is built up.

The method of proceedure in the former case may be well illustrated by that followed in Winnepeg, Canada, where the subsoil in many spots is very wet. Trenches, running transversely across the street and spaced about twenty-five feet apart, are dug to a depth of six inches. These connect with similar trenches running parallel with the center line of the street under the curb line. Drainage outlets are secured at the storm

basins at the intersections of the streets. The ditches are filled with broken rock. The sub-base is then rolled to a solid surface and covered by three inches of clean sand. Upon this sand is laid the hydraulic concrete foundation. In the case of built-up road beds, a hydraulic concrete of the best quality must be used for the foundation. For here more than in any other case is needed a firm, impervious bridge and support for the material above it.

Since the use of old brick pavements, and macadam, plain or bituminous, have not proven complete successes for foundations, many authorities have come to the conclusion that a foundation of Portland cement concrete or a good grade of natural cement concrete is practically a necessity for a perfectly stable asphalt pavement. The principal objection to a macadam foundation is that the stone in the macadam rolls frequently under the pressure of the steam roller, and consequently the proper compression is not given to the asphaltic wearing coat. The result is that the pavement is made subject to surface integration. In a report from Marshalltown, Iowa, in 1907, the unstability of the stones in the macadam foundation was given as the reason for the failure of 7701 square yards of asphalt pavement laid in 1903. At this juncture, it may be said, however, that at the present time the City of Chicago claims to have in use and to be constructing pavements upon macadam with excellent success. This proceedure has been followed because it was almost impossible to keep traffic off from the new work long enough to allow concrete to set properly and acquire its maximum effi-

ciency. From this last case it may be concluded that, although many failures have occurred in pavements laid upon macadam, it may be used with success by properly compacting it before the laying of the upper asphaltic courses.

The principal advantages of a concrete foundation for an asphaltic pavement are that (a) it is a permanent structure, increasing in strength as it ages; (b) it distributes the concentrated loads over a considerable area of subgrades; (c) it is impervious to water; (d) it gives a uniform surface upon which to lay the asphalt pavement; (e) It acts as a bridge to support the courses above it. Theoretically to secure the greatest strength at the least cost, the proportions of the ingredients of the concrete should be so adjusted that the voids in the sand will be filled with a cement paste, and the voids in the gravel and rock with cement mortar. The cement is the most expensive ingredient and is usually the weakest, so that if more of it is used than is necessary, the cost becomes needlessly greater with a corresponding decrease in the strength of the concrete.

Occasionally asphalt is laid upon bituminous cement concrete. The chief advantages, claimed for this type, are, (1) that the asphalt wearing coat adheres to it more firmly than to the hydraulic concrete; and (2) that the time required for hardening is very much reduced. On the other hand, the bituminous concrete is weaker, less reliable, and usually more expensive than the hydraulic concrete. Further the bituminous concrete is much more difficult to handle when repairs are being made since it is nearly impossible to separate the top coat from the foundation.

The purpose of a binder course is to bind the wearing coat and the foundation together, and to prevent the wearing coat from being pushed along in waves by traffic. As a rule the binder consists of broken rock that will pass an inch ring, and enough limestone filler and asphaltic cement to fill all the voids. The composition of a binder course, graded by percentages of the whole, which is often required by many municipalities is shown in Table II.

Table II.

Composition of Binder Course in Percentages.[1]

Material	Percentages
Bitumen.	6.6
Filler (Crushed limestone)	7.4
Sand	28.0
Stone (passing 1/4" screen).	22.5
Stone (passing 1/2" screen).	23.0
Stone (passing 1" screen).	12.5
Total, ...	100.0

1. The Modern Asphalt Pavement by Richardson, p. 25.

A binder, greater than one and one half inches thick as well as stones or gravel over one half inch in the greatest dimension should be avoided. The thick binder with large stones causes large voids, prevents the giving of the proper compression in rolling of the surface, and causes the surface to break into the voids under heavy loads. The stones may be moved by the

steam roller in rolling the surface, or by the heavy traffic after the construction has been completed, in such a manner that the breaking of the surface is inevitable. An excess of fine sand is also undesirable, since more asphaltic cement is required to coat the total surface, and since the necessary jagged edges of the upper and lower surfaces are diminished in roughness.

The amount of asphalt cement necessary to coat satisfactorily the stone of a binder course can only be determined by experiment. The character of the stone, the filler and the asphalt cement are the governing factors. The amount of cement should not be so great as to allow it to run off of the hot stone or too little to give a bright glossy color. If there is an excess of cement, it may collect in pools or spots, and be drawn by the hot summer sun into the wearing coat, which is thereby softened. On the other hand a slight and well distributed excess may benefit a street having light traffic, under which the surface would ordinarily be apt to crack. In this case, the enriching of the wearing coat with asphalt cement causes a preservation. An example of this enrichment was noticed several years ago in a western city, and from analyses of specimens taken from different parts of the pavement, the results, as stated in table III, were secured.

The table shows that there is 0.75 per cent more bitumen in the bottom of the course than in the top. The grading of the sand is approximately uniform, so that it is evident that no accident occurred in mixing.

Table III.

Chemical and Physical Analysis of Top Coat.

Section	Bitu-men	Per cent remaining on Mesh.							
		200	100	80	50	40	30	20	10
Top	9.8	12.2	10	31	32	3	1	1	0
Duplicate	9.8	11.2	10	31	33	3	1	1	0
Bottom	10.3	11.7	10	32	32	2	1	1	0
Duplicate	10.7	11.3	10	33	31	2	1	1	0

1. From Richardson's Modern Asphalt Pavements, p. 23.

Table IV shows the results of the same kind of an analysis, as above, performed by the author in the University road laboratory, of a specimen taken from the wearing coat of a pavement constructed of Trinidad asphalt in Waterloo, Iowa. The very slight variation of the amount of bitumen shows that no enrichment has occurred by the passage of bitumen from the binder into the wearing course in this case.

Table IV.

Section	Bitu-men	Amount passing mesh 200 Per cent	Percent remaining on Mesh					
			200	100	74	40	20	10
Top	9.50	6.0	3.0	10.5	36.0	25.	10	0
Bottom	9.55	5.95	3.9	10.5	35.1	26.	10	0

The consistency of the asphalt cement in the binder should be softer than that used in the surface coat for several reasons. The binder course is a very open material which permits the evaporation of the oils from the asphalt cement by the

heat of the stone. As a result the cement becomes much hardened and more brittle. Further a stronger bond is secured between the fragments of the binder rock by the use of an asphalt cement of a softer consistency. The cement for the wearing coat is mixed to a consistency represented by a penetration of 35° to 50° with the Dow needle, while the cement for the binder course has a penetration of from 75° to 80°.

The binder course as described above is a modification of the open binder to the extent of the use of fine crushed stone or other fine material to fill the voids, so numerous in the latter. An intermediate course with no voids practically is in itself an element of great strength, and by its use the surface coat can safely be reduced to a thickness of one inch for ordinary streets and one and one-half inches for streets having heavy traffic.

It is now found, however, that the use of a binder course may be entirely eliminated by the proper painting of the concrete foundation with asphalt cement. In this case the surface coat unites with the artificial base so closely that in the removal of the surface, the fracture will occur within the concrete rather than at the joint.

The wearing coat is made from an artificial mixture of sand and asphalt cement, heated to about 275° to 325° Fahrenheit. Enough cement must be used to fill all the voids in the compacted sand, so as to secure a maximum binding force between the mineral particles. An excess of cement must be avoided for the reasons mentioned in the discussion of the binder course. Further an

excess of asphalt cement causes the wearing coat to flow under traffic during warm weather, and causes the surface to chip and scale off during cold weather. The purity of the cement is not a matter of importance, since the more mineral matter there is in the composition, the less sand and pulverized limestone will be needed. It is customary to grade asphalt cement, according to the amount of bitumen soluble in carbon-bi-sulphide, which the completed pavement must contain. In the southern cities, owing to the long hot summers, more than nine to twelve per cent is not allowable, while in the north, the liberal amount of twelve to fifteen per cent may be used. Of course, the amount required varies with the character of the travel, the climate, and especially with the quality and physical character of the material at hand.

The proportions of the ingredients of the surface coat of an asphalt pavement were formerly expressed in percentages of the weight of the whole mixture; however, the proportioning by the number of pounds of each kind of material is coming into favor at the present time. The table below shows a comparison between the two methods.

Table V.[1]

Materials	Weight lbs.	Proportions of weight Per cent.
Sand	50	80
Pulverized limestone	5	8
Asphalt cement	7-1/2	12
	62-1/2	100

1. Baker's Roads and Pavements, p. 415.

Formerly it was customary to express the composition of the wearing coat about as follows:-

Sand.	70 to 83 per cent
Pulverized limestone. .	3 to 15 per cent
Asphalt cement.	12 to 15 per cent.

Defects and Deteriorations.

The causes of defects and deteriorations in asphaltic street construction can be grouped into three general classes, namely, (1) those due to defective construction; (2) those due to unfavorable environments; and, (3) those due to age.

The first thought of defective construction immediately recalls the subject of improper specifications. Up to 1893, asphalt paving specifications used in the cities of the United States were practically closed to all asphalts but one, that coming from one portion of the Island of Trinidad on the South American coast. The quality of the pavements laid was not uniform. The same contractor under the same specifications very often laid a good stable pavement on one street and a very poor one on an adjoining street. Much mystification was experienced, because the secrets of the good construction of an asphalt pavement were monopolized entirely by the trade. The engineers of our cities in consequence of their limited knowledge, allowed each bidder to prepare his own formulae for proportioning and mixing the ingredients. Inspections on asphalt portions of pavements were farces. Few cities maintained laboratories, and, where one was in use, the exact requisitions of a good pavement were often either unknown or misunderstood.

Believing that better progress could be made and lower prices obtained by opening to competition the specifications for asphalt street construction, Andrew Rosewater, in 1893, prepared a standard set of specifications for the city of Omaha, Nebraska.

This admitted all asphalts under the usual bonds and guarantee provisions. All the larger cities were induced to cooperate with the city mentioned; and the complete change of conditions resulting opened the way for a more healthy relation between the producers and those, benefited by the improvements. The opposition to open specifications was at first formidable and stubborn, but in the end was futile. The asphalt from Utah, California, Kentucky and Venezuela found a market.

The inferiority of the asphalt from the above sources has long been considered one of the principal reasons for failures of asphalt pavements. This contention is a just and true one, and the engineer in drawing up the specifications should safeguard himself against the use of poor materials. On the other hand, he must be certain that the requirements serve their original purpose and do not subject his constituents to undue expense. For instance, in the Manhattan Borough of New York and in a few other cities of the United States, the specifications for asphalt pavements exclude all asphalts, which, in their commercial form, contain less than ninety percent of bitumen. Such specifications do not protect the public against poor pavements, but increase their cost by the exclusion of competition.

The common method of comparing asphalts according to their alleged purity which is based upon the bitumen they contain, is both incorrect, and formulated to deceive. It is merely an instrument of the so-called trust contractors to bankrupt the so-called anti-trust contractors. As a matter of fact the quantity of bitumen in the commercial asphalt product is simply

a commercial question, which is governed by freight rates and other similar factors. Pavement mixtures, laid with an asphalt, containing ninety per cent of bitumen in its commercial state, are no better or worse than those from an asphalt containing five per cent. In each case from ten per cent to fifteen per cent of extracted bitumen of a specified quality is required and used in the mixture, the exact proportioning varying with the grading of the sand.

This variation of the grades of sand has proven itself to be one of the governing factors in the construction of a stable and lasting pavement. In the first place, the sand should be clean, sharp, hard and tough enough to be not easily crushed or broken, and should contain as small a proportion of voids as possible. It should be free from loam, clay, and vegetable matter, as each and all of these are completely devoid of cementing material and offer very little resistance to crushing loads. The sand should have sharp angular grains rather than smooth round ones, since the former affords a better surface for the adhesion of the asphaltic cement. In order to secure a minimum number of voids in the construction of an asphalt surface coarse, there should be a certain proportion of mineral particles, one tenth inch in diameter, one twentieth inch, decreasing in size to impalpable dust. This dust or filler consists sometimes of Portland cement, more often of crushed limestone, to a volume of five per cent of the completed courses. A sufficient amount of one hundred and eighty mesh material is needed to avoid the balling up of the fine dust, and the ten, twenty and thirty mesh

material is a necessity to provide for a rough surface as well as to give enough compressive strength to the pavement to carry the traffic.

It has become very evident from what has been said in the previous pages that the amount of bitumen or asphaltic cement in any mixture is very variable, depending upon the grading of the mineral aggregate and the peculiar surface of the sand grains. Table VI illustrates this fact very plainly. The sands found and in use in Moline, Illinois, in 1902, would carry but eight and five-tenths per cent of bitumen while in Paris, France, and London, England, eleven and five-tenths could be used, and in Glasgow, Scotland and Seattle, Washington over twelve and five tenths per cent.

Table VI[1]

	Moline	Paris	London	Glasgow	Seattle
Bitumen soluble in CS_2	8.4	11.2	11.1	12.0	12.3
Passing 200 mesh seive	15.6	14.7	15.3	18.0	12.7
" 100 " "	14.0	18.7	12.7	15.0	11.0
" 80 " "	4.0	23.1	20.5	25.0	9.0
" 50 " "	16.0	26.3	33.7	24.0	23.0
" 40 " "	17.0	3.9	3.6	4.0	15.0
" 30 " "	13.0	1.6	1.5	2.0	10.0
" 20 " "	9.0	0.4	1.1	0.0	5.0
" 10 " "	3.0	0.1	0.5	0.0	2.0
Total,	100.0	100.0	100.0	100.0	100.0

1. Richardson's Modern Asphalt Pavements, p. 341.

In order to state in a condensed form what a set of specifications for an asphaltic wearing coat consists of, the following specifications and facts and tests, upon which they are based, will be stated briefly:-

(a) Classification of bitumen.

1. Natural asphalts, occurring as such in nature, and refined merely by removing the water, light oils, and grosser mineral impurities. Such are the Trinidad and Bermudez asphalts. They are considered to be the best upon the market, because the chemical and physical characteristics of the bitumen are well defined and recognized, and the proper methods of handling are well established.

2. Combinations in which hard natural asphalts, containing less than 60 per cent of bitumen soluble in standard naphtha, are refined and used commercially with asphaltic oils. This class has come into permanent use only since asphaltic oils have been placed upon the market. So far, when used intelligently, they have proven a success. Their use should be regulated, however, according to the thoroughness of inspection, kind of traffic, and the skill and reliability of the contractors and supply agents.

3. Solid residues produced by distillation or oxidation of petroleum. This third class of bitumens are, on account of the present manner of production, uncertain in quality. Some are good, others are bad. The California oil residues, when carefully prepared, are excel-

lent materials, and are used extensively throughout the United States for paving purposes. However, the commercial asphalts of this class, at present vary so greatly in quality, consistency and stability that they are not universally recommended.

(b) Characteristics of asphalt, to be determined by chemical tests:

1. They must not contain more than 3 per cent of their bitumens insoluble in cold carbon-tetra-chloride.
2. Their bitumens must not yield on ignition more than 18 per cent of fixed carbon.
3. Their bitumens should consist of 60 per cent of malthene, i.e. material soluble in standard petroleum ether. When less than this amount of malthene is present the asphalt should never be used without an asphaltic flux.
4. When fluxed into an asphalt cement of the consistency used, the asphalt should not lose over 5 per cent of material on heating for seven hours at 325° Fahrenheit, nor should its consistency be decreased by more than 60 per cent of the original consistency.
5. The penetration, when the asphalt is fluxed into an asphalt cement, should not be less than 10 at 32° Fahrenheit nor more than 350 points at 115° Fahrenheit.

(c) Method of determining amount of bitumen in paving material:-[1]

1. A definite quantity of material is treated with a specified amount of carbon-bi-sulphide at ordinary temperatures. This is allowed to stand undisturbed for a

1 American Society for Testing Materials.

sufficient length of time to permit the subsidiation of the insoluble matter. The solution is then decanted off into another receptacle and the residue again treated with the solvent.

2. After standing a second time for subsidency, the two solutions are filtered through a "Gooch" crucible, fitted with an asbestos plug. The filtrate is then evaporated down and the residual bitumen burned off. The weight of the ash, added to that of the residues in the receptacles is equal to the asphalt with all the bitumen extracted. Therefore, the difference between the weights of the original specimen and this latter weight is the weight of the bitumen in the asphalt.

(d) Specifications of the City of Chicago for an asphalt top course, (Proportions):--

1. Bitumen soluble in cold CS_2 = 10.5 per cent to 13 per cent.
2. Portland cement and mineral dust passing a 200 mesh sieve = 12.0 per cent to 18.0 per cent.
3. Sand passing an 80 mesh sieve = 18.0 to 36 per cent.
4. Sand passing a 40 mesh sieve = 30.0 to 50.0 per cent.
5. Sand passing a 10 mesh sieve = 8.0 to 20.0 per cent.

(e) Davenport Specifications for wearing coat.

I. Bermudez Asphalt:-

1. Cementing material prepared from best quality of pure Bermudez asphaltum mined and dug from so-called asphalt or pitch lake, and unmixed with any of the products of coal tar or any other inferior bituminous products. It must be fixed with liquid as-

phaltum of heavy petroleum oil.

2. The heavy petroleum oil the residuum obtained by the distillation of petroleum, will be free from water, light oils, and other objectionable impurities. The specific gravity must be from eighteen degrees (18°) to twenty-three degrees(23°) Beaume. The oil must bear a fire test of three hundred and fifty degrees (350°) Fahrenheit.

3. The refined asphalt shall be mixed in the following ratio by weight:-

(a') Heavy petroleum oil, 13 to 20.

(b') Refined asphalt cement, 100.

II. Wearing surface shall consist of,

1. Asphaltic cement.	9	to	15	per cent
2. Sand.	88	to	74	per cent
3. Pulverized carbonate of lime. .	3	to	11	per cent
	100		100	

III Sand and carbonate of lime.

In order to make a pavement homogeneous, the proportions of asphaltic cement must be varied. Carbonate of lime may be reduced or omitted entirely when suitable sand is used. Sand and asphaltic cement will be heated separately to about three hundred degrees (300°) Fahrenheit. The carbonate of lime must be mixed cold with the hotsand with the required proportions, and this mixture then must be mixed with the hot cement.

IV Compression of surface:

Surfaces will be compressed and rolled by a steam roller weighing not less than two hundred and fifty pounds (250 lbs.) per square inch until the wearing coat will have a thickness of one and one-half inches (1-1/2") and no impressions are left on the surface from rolling.

(f) Des Moines Specifications for wearing coat.

I The asphalt employed must be of a solid, native bitumen, having been obtained from a natural deposit, and having been in use in the paving industry for at least five (5) years.

II When asphalt is tested at 32° Fahrenheit, a penetration must be shown of not less than ten, and when tested at 115° Fahrenheit, a penetration of not less than 350° (Dow standard). When a briquette of pure bitumen, having a minimum cross-section of one square centimeter, is tested for ductility at seventy-seven degrees (77°) Fahrenheit, the bitumen must stretch to a distance of eight (8) centimeters before breaking.

III When the bitumen is heated in an open tin pan at a temperature of three hundred (300°) degrees Fahrenheit for eighteen (18) hours in a hot oven, it must not show a loss by volatilization of over five (5%) per cent, and must not have been hardened over fifty (50%) per cent by this heating.

IV The oil used for flux in the manufacture of asphaltic cement shall be the residue from any satisfactory pe-

troleum from which the lighter oils have been removed by distillation without cracking. It must have a specific gravity of from seventeen (17°) to twenty-five (25°) degrees (Beaume). The oil will not flash below three hundred and twenty-five (325°) Fahrenheit, and volatize more than five (5%) per cent on heating seven (7) hours at three hundred and twenty-five (325°) degrees Fahrenheit.

V Sand - Whole must pass through a number ten (No. 10) mesh screen, fifteen (15%) per cent shall pass an eighty (80) mesh screen, and at least seven (7%) per cent pass through a one hundred (100) mesh screen.

VI The filler must consist of a powdered mineral matter of such a degree of fineness that the whole of it will pass a number fifty (50) mesh screen, and at least sixty-six (66%) per cent through a two hundred (200) mesh screen. Portland cement may be used as a filler.

After all of the destructive elements encountered in the choice of the materials and in the chemical preparation of the ingredients have been safe-guarded against, the next consideration of importance is that of the workmanship in the mixing and construction of the binder and top courses. In fact from the beginning of the heating of the ingredients at the asphalt plant to the final compression in the street, there is required the most careful supervision and most skillful work on the part of the foreman and his workmen. It is unfortunate that the immediate profits of the work is often the first consideration to the

contractor who rushes the work to completion in a careless and irresponsible manner without a thought of what will result from his hap-hazard methods.

This haste results in a number of common errors in the manufacture of asphalt mixtures which can be summarized as follows:--

(a) The amount of bitumen is deficient. This is caused by the neglect to properly proportion the mixture or by the introduction of sediment into the cement by working the tank too low.

(b) The mixture on account of over heating is too stiff.

(c) The improper proportioning of the amount of flux and asphalt, or the amount of asphaltic cement and sand causes either too stiff or too soft a mixture.

(d) The improper mixing of the petroleum residuum with asphalt causes an incomplete blending of the oil with the asphalt; and soft spots in the pavement result.

In the preparation of the binder course, the broken stone, properly screened, is heated in a revolving drum to a temperature of about 300° Fahrenheit. The hot stone is fed into an incline steel cylinder, on the axle of which are steel blades. These push the material through the drum and mechanically mix the rock and asphalt cement which is constantly dripping upon the rock material from a feed tank above. Considerable skill is required in maintaining the proper proportions and the required temperature of both the rock and the cement. Each rock should be coated with cement, but there should be no excess of

the latter. If there is more cement used than is necessary the surplus will probably be lost between the plant and the street. On the other hand, if too little cement is used, the stone will not adhere well together, and the whole course may break up under the weight of the steam roller. On the concrete foundation, which must be cleaned of all refuse, the binder should be distributed uniformly, and be compacted until a firm, bright, and glossy surface is secured.

In the preparation of the asphaltic cement and sand for the wearing coat, each is heated separately to a temperature of 275° to 300° Fahrenheit. After a proper proportioning by weight, the ingredients are dumped into a mechanical mixer with interlocking blades, and continuously mixed for one and one half to two minutes. The operation of mixing the sand and cement requires care, (1) to proportion the mixture accurately, (2) to mix the material thoroughly, (3) to secure and maintain the required uniform temperature, and, (4) to complete the process of mixing without overheating the cement. From the mixer, the material is dumped into carts or dump-wagons and transported to the street. Each wagon is equipped with a covering of canvass, so that a minimum amount of heat is lost in the passage from the plant to the works. The most economical wagon for asphalt portage is the end-dump, lined with iron plating. By the use of this type the process of dumping is much simplified, and the amount of asphalt lost by sticking to the sides and bottom of the conveyor, reduced.

In the laying of the wearing coat, precaution should be

taken that no foreign materials such as cigar stumps, leaves, straw, bits of paper, etc., are mixed in with the course. During the passage of the mixture to the street a considerable amount of the asphalt cement will naturally be jolted to the bottom of the wagon. Owing to this fact, the load should be dumped at the side of the place where it is to be spread, and thence shoveled into place, in order to avoid the concentration of asphalt cement in spots, and the deteriorations resulting from such a defect. Great care should be observed in spreading and rolling the course to a uniform thickness. If uniformity in depth is not maintained, there results the formation of depressions after the final compression. This causes an uneven wearing, due to the continuous shocks, however slight at first, by wheels of vehicles passing over the effected spots.

Deteriorations of asphalt pavements are not always chargeable to the defects of construction just classified. All materials are constantly undergoing changes due to the action of the elements. Hence the ordinary wear and natural decay of asphalt pavements are not conditions that can be prevented, but are conditions whose effects can be minimized to such an extent as to lengthen the life of the pavement from five to ten years. All asphalts gradually lose their cementing power by oxidation, volatilization and evaporation. The asphalt pavements are continually exposed to the action of the sun's heat, and to the combined action of water, air, or acids and alkalies, due to the decomposition of organic matter. These are the agencies which the engineers are consistently attempting to curb.

In the gradual destruction of the pavements, it has been observed that the modes of disintegration have been generally:-

(a) Disintegration by cracking in long single fissures that continue to extend with time.

(b) Disintegration by the sliding of the surface coat on the binder course.

(c) Disintegration in spots, where the top coat is gradually worn through, and the binder course pierced.

The causes of the formation of cracks in asphalt pavements may be classified as follows:-

(a) Defective asphalt cement.

(b) Deficiency in bitumen so that the surface course does not have sufficient tensile strength and elasticity to withstand the contraction and expansion due to the variations of temperature.

(c) Unsuitable sands and consequently the lack of adhesion between the asphalt cement and pebbles.

(d) Defective foundation and lack of support, especially along the rails of street car lines, and around manholes.

The question of the tensile strength of the asphalt surface course is one of the very important problems to be solved in the process of successful asphalt pavement construction. The following tables show that nearly every property of the ingredients have some influence on the strength of the course.

Table VII.

Effect of Quantity of Asphalt Cement on Strength of Surface.[1]

Amount	Crushing Strength		Shearing Strength	
	36° F.	77° F.	36° F.	77° F.
Trinidad Cement	(Washington Mixture lb. per sq. inch)			
Normal 15 %	1703	880	2865	1425
More cement 16.5%	2425	768	2882	2378
Bermudez Cement				
Normal 10%	2416	741	3193	1528
More cement 11%	2544	961	2511	1636

1 Richardson's Modern Asphalt Pavement, p. 456.

Table VIII.

Effect of Increase of Amount of Dust

In Surface Mixture on Tensile Strength [1]

Dust Per Cent	Trinidad 36° F.	Bermudez 36° F.	Trinidad 77° F.	Bermudez 77° F.
7.5	501	449	188	111
10.0	604	611	205	171
15.0	646	662	273	186
20.0	701	857	270	192

1.Richardson's Modern Asphalt Pavement, p. 457.

Table IX.

Effect of Density on Strength of Surface

Compaction	Tensile Strength lb/sq. in.			Density
	40° F.	77° F.	90° F.	
Least Dense	463	152	101	2.08
Densest	646	273	166	2.23

Table X.

Effect of Sand Grading on the Strength of Surface [1]

Composition	Bitumen	Passing Mesh 200	100	80	50	40	30	20	10	Ten.Str.#/in 38°F.	78°F.
N. Y.	10.6	14.4	11.0	12.0	27.0	11.0	7.0	4.0	3.0	568	300
Wash.	10.5	9.7	3.2	3.4	22.3	20.5	13.2	7.8	7.4	604	205

1. Richardson's Modern Asphalt Pavement, p. 458.

Table XI.

Effect of the Character of Bitumen on the Crushing Strength of Wearing Coat.[1]

(Mixtures of Coal Tar, Trinidad Lake, and Pedernales Asphalt)

(10% of Dust and Washington Sand in All Mixtures)

Mixtures	Density	Strength lbs/sq.in. 38° F.	77° F.
Coal Tar, 15 per cent	2.16	3880	1254
Coal Tar, 10 per cent	2.07	3845	2655
Land Pitch Cement, 15% or (10% bitumen)	2.13	1813	761
Bermudez cement, 10% or (10% bitumen)	2.10	1955	635
Pedernales asphalt 10% or (10% bitumen)	2.06	2125	550
Lake Pitch cement 15% or (10% bitumen)	2.14	1375	548

1. Richardson's Modern Asphalt Pavement, p. 456.

As a whole these physical tests illustrate the peculiarities of mixtures of varying composition, and indicate conditions that must be met and overcome by the engineer to avoid cracking and other defects of like nature.

Long cracks are usually due to the contraction of as-

phalt surfaces, when cold. They are found extending transversely across the streets from the gutters and radiating from iron catch-basins, lamp-holes, manholes, etc. It has also been noticed that these cracks occur sooner and increase more rapidly on a street having light traffic. In fact they are seldom found on a heavily traveled thoroughfare, unless the material used in its construction was prepared with very poor judgment. If cracks occur in a pavement upon a good foundation, very good evidence is given that either the paving mixture has insufficient bitumen, or the asphalt cement used is too hard. The harder or less plastic an asphalt cement is, the more liable the pavement is to crack, when subjected to extreme heat and cold.

The following tests were made in the road laboratory to determine the effect of heat on asphalt. The heat, secured from electric lights underneath the baking oven, was kept constant at 110° Fahrenheit. The specimens were taken from a Bermudez asphalt top coat mixture used for street paving in Waterloo, Iowa, in 1907. This asphalt was moulded in a die into cylinders, one inch in length and one inch in diameter under the impact of one hundred and ten blows of a Beaume hammer. The hammer weighed five pounds and had a fall of four inches to the die plunger. The conditions produced by this method was considered to be as near similar to those existing in the pavement as could be gotten under the circumstances. These tests were performed on an impact testing machine. The plunger of the machine weighed 4.4 milograms, and was raised and tripped automatically at the will of the operator. The impact surface was in the shape of a cone having a maximum radius of one centimeter.

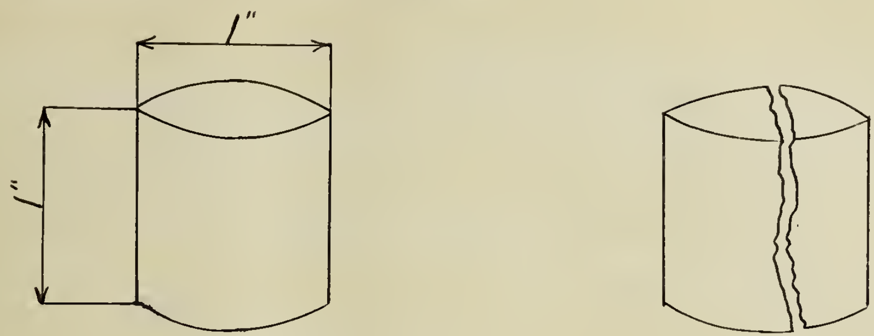
Table XII.

Sample	Specimen	Time Bak'g Weeks	Maximum ht. plunger cm.	Blows for Failure. Indication	Develop	Final	Remarks.
	1	No Bak'g	10	5	7	10	70° F.
Bermudez	2	2	10	4	6	10	70° F.
	3	2	10	5	7	10	70° F.
Asphalt	4	3	9	5	7	9	70° F.
	5	3	12	11	12	12	70° F.
Wearing	6	4	10	8	9	10	70° F.
	7	4	10	8	9	10	70° F.
Course	8	5	7	5	6	7	70° F.
	9	5	9	6	7	8	70° F.
Material	10	6	7	5	6	7	70° F.
	11	6	7	5	6	7	70° F.
	12	7	8	6	7	8	70° F.
	13	7	9	7	8	9	70° F.

Note - For the first blow the plunger is raised one centimeter, and for each succeeding blow is raised an additional centimeter.

The first column under "Blows for Failure" shows under what blow the first indications of cracking appear; the second gives the number of blows to produce well developed cracks; and the third, the number of blows to cause complete failure.

It is evident from the above that the longer the specimens were baked, the weaker they became. As they failed always by cracking in a plane normal to the upper and lower surfaces, as indicated in the figure below, a conclusion can be made that the stress was more tensile in character than compressive, and that the real cause of the failure was due to the reduction of the adhesive power of the cement by a volatilization of the oils and a hardening of the bitumen.



Another kind of disintegration, resulting from the rolling and crowding of the courses, occurs in pavements in which the top course is too soft and in which the bond between the courses is defective. The lack of binding power between the binder course and foundation is usually caused either by the use of gravel or an excess of hydraulic cement in the foundation. The bond between the binder and top courses may be made defective by the use of too rich an asphalt cement, or by neglecting to clean thoroughly the upper surface of the binder course before laying the wearing coat. The tendency of the traffic to push the top coat up in waves or to crowd it into the gutter can not be entirely guarded against on streets with an excessive amount of travel, or where traffic is confined to a comparatively nar-

row strip of the street. A surface mixture to withstand heavy traffic without any rolling (a) should be constructed with moderately sharp sand, grains angular yet free from jagged edges; (b) should consist of sand grains graded from coarse to fine, and having at least 25 per cent passing an eighty mesh sieve and about 17 per cent passing a one hundred mesh seive; (c) should have in its composition at least five per cent of fine powdered limestone; and (d) should contain a sufficient amount of moderately soft asphalt cement.

In several cases of disintegration on record, it has been observed that, with the rolling of the top coat, occurred the formation of cracks. This is due usually to the working of oils from the binder course up into the wearing coat. The first evidence of disintegration is marked by the formation of a slight depression over the affected spot. Then appear transverse cracks followed by longitudinal ones until the pavement has the appearance of an alligator skin. If the top coat is cut through in the earlier stages of the action, the lower part will be found to be softening. Later the upper surface will be affected in the same manner.

Disintegration of the surface in various parts resulting in the formation of depressions or holes extending to the base is the commonest of all the defects in asphalt surfaces. However, the best of mixtures will be affected in the same manner by unfavorable environments. Deteriorations of this class may be summed up as those due (a) to a weak base, (b) to inferior mixtures, (c) to the action of illuminating gas, and, (d)

to the action of water and acids in their several different stages of purity. The first two causes have been too thoroughly discussed in the preceding pages to require any repetition. Both are, of course, brought about by careless work.

Illuminating gas escaping from leaky pipes under the pavement has been found to be absorbed by the latter, and when concentrated enough to become a very destructive agent. The failing part has the same appearance as it would have if affected by oil, with the exception that fine hair-like cracks running along the street occur before any waviness of the surface appears. Specimens taken from the affected part smell very strongly of gas and when heated will emit enough gas into a closed tube to flash on ignition.

Mr. Richardson, director of the New York testing laboratory, in the course of his work in experimenting on such affected portions of surface coating, determined the analysis of the gas in the specimen, and then made a comparison of the results with the common analysis of illuminating gas. The analyses of both gases are given in Table XIII.

Upon comparing these two compositions, it is seen that they are not at all similar, and it does not seem possible that the latter gas could originate from the former. However, the heavy hydrocarbons to which class asphalt belongs, absorb other lighter gaseous hydrocarbons, and therefore the ingredients of the illuminating gas which the asphalt would have the greatest affinity for, would be the hydrocarbon gas and some of the methane. Thus what gases would be expected to be in the affected

Table XIII.

Analyses of Illuminating Gas and Gas found in Asphalt.[1]

Composition	Illuminating Gas	Gas in Asphalt.
Carbon-di-oxide	0.2%	8.4%
Oxygen	0.0	10.8
Heavy hydrocarbons	12.1	13.4
Carbon-monoxide	25.5	0.7
Hydrogen	39.2	6.6
Methane	23.0	2.0
Nitrogen	0.0	58.1
Total,	100.0	100.0

1. Modern Asphalt Pavements by Richardson, p. 462.

pavement would be carbon-dioxide from the air, and the constituents of the illuminating gas with the hydrocarbons very much in excess.

Mr. Richardson practically demonstrates that the above takes place when asphalt is in contact with illuminating gas by taking two samples from the gas tap in the laboratory, analyzing one immediately and placing the other in a tube whose interior surface was coated with asphalt. After several weeks this latter gas was analyzed. From the results as shown in table XIV, it is evident that the asphalt absorbed over five percent of the hydrocarbons, a small amount of methane, and nothing else.

There is only one way to stop disintegration by gas, and that is to stop the leakage of the gas. Any repairs made will soon be as bad as the original pavement, if the gas still

continues to pass into the construction.

Table XIV

Ingredients	Original Gas	Gas after Asphalt Absorption
Carbon-dioxide	0.2%	0.1%
Oxygen	0.0	0.0
Heavy hydrocarbons	12.1	7.2
Carbon monoxide	25.5	27.3
Hydrogen	39.2	42.2
Methane	23.0	23.2
Nitrogen	0.0	0.0
	100.0	100.0

Modern Asphalt Pavements by Richardson, p. 463.

Tests for the absorption of gas and the deterioration resulting were made in the laboratory by the writer. Under the conditions in which the tests were made, it was found that the absorption was much faster than the deterioration if there was any of the latter at all. The results are as shown in table XV. The specimens were cylinders of the same size and shape as used in the impact tests in the previous pages.

Table XV.

Material	Agent	Weight - Grams.						
		1 week	2 week	3 week	4 week	5 week	6 week	7 week
Bermudez Asphalt topcoat	Gas	26.3995	26.9495	26.9522	26.9522	26.9550	26.9572	26.9577
	Gas and Water	26.9815	26.9820	26.9842	26.9869	26.9870	26.9870	26.9875

From the results of the above table, it was found that the absorption of gas in percentages of the weight of the specimen were two and one-tenth per cent and two and three tenths per cent, respectively. From the amount absorbed, the great affinity of asphalt for some of the ingredients of gas can be judged.

The action of water on asphalt has been a prominent topic of discussion from the early days of the industry. Richardson says "A well constructed asphalt pavement should not be affected by water during its life-time". However, when any defects occur in the nature of the asphalt in the construction, and in the foundation, the water becomes an element of much importance. In London during the year 1894, pavements of Trinidad asphalt were laid by the most modern methods and have withstood to the present time the action of fogs and continued wet weather. Bermudez asphalt did not fair so well and has been worn considerable by heavy traffic.

Unfortunately in some cases, adequate provisions cannot be secured to prevent the action of water, due (a) to the presence of a porour base, (b) to the seepage of water into the sub-base from terraces of a higher elevation than the street, and (c) to poorly arranged street grades. In the latter case the greatest difficulty is to prevent the street water from collecting in pools along the gutter and in other slight depressions. This water contains usually every kind of filth collecting upon the street, such as decaying leaves, manures, horse urine, and liquid refuses thrown onto the streets by careless inhabitants. In Reading, Pennsylvania, a Bermudez asphalt pavement has been com-

pletely ruined by the action of house drainage water which was conducted along the gutters to the inlets of the storm sewers. Ammonia from manures will rot the asphalt surface quicker than any other single agent. All errors in the preparation of the sub-base and in the construction of the pavement increase the susceptibility of the pavement to the action of water.

In warm weather the first defect noticeable will be a softening and crowding of the upper surface due to the rotten conditions of the bond between the courses. In one case a wearing course giving strong indications of disintegration in this manner was pierced and the sand was found to be completely void of all cement material. In the winter theaction will be noticed by the crumbling away of the affected surface under traffic.

Streets should be swept clean with the use of as small amount of water as possible. Some authorities believe that more damage is done by the washing of the streets than by the water falling on and draining off into the gutter. The tables of results from experiments performed in the road laboratory by the author show very clearly what can be expected from unclean conditions of the street.

The object of the experiments was to determine the relative action of the common destructive agents upon different asphalt top coat materials. All samples used in these tests were taken from the top coat used for paving purposes in Waterloo, Iowa, in 1907. The specimens were moulded into cylinders under 110 blows of the Beaume hammer, as previously explained, before any testing was begun.

Action of Common Destructive Agents upon Asphalt.

Experiment 1.

Specimen - Bermudez wearing coat material.

Agent - Sewer water, taken from sewer outlet for drainage of horse barns.

Deteriorations in Percentages of Original Weight of Specimens

Intervals Weeks	Weight-Grams		Deteriorations Dry weight Percent	Observations
	Saturated	Dried		
0	-------	26.7516	----	Specimen in very good condition sand and cement well mixed. Mass very solid, and porosity a minimum.
1	27.2710	26.7225	0.11	Slight decrease in weight, but no deteriorating action observed.
2	27.1415	26.7028	0.19	Continued decrease in weight and indications of pitting.
3	27.1350	26.6242	0.48	Continued decrease in weight.
4	27.0510	26.6225	0.52	An increased amount of softening and pitting appears.
5	27.1251	26.5695	0.68	Same characteristics as preceding week.
6	27.1439	26.5605	0.71	The decrease in weight, the pitting of the surface of the specimen, and the increasing softness of the mass indicates that sewer water decreases the life of cement and the ability of the asphalt to hold the mineral ingredients in a solid mass.
7	27.1391	26.5590	0.72	
	Total,		0.72	

Experiment 2.

Specimen - Bermudez asphalt wearing coat.

Agent - Ordinary rain water.

Deteriorations in percentages of Original Weight of Specimens

Intervals Weeks	Weight-Grams Saturated	Dried	Deteriorations dry wgt. per cent	Observations.
0	-------	27.1450	-----	Specimen in very good condition. Sand and cement well mixed, extremely solid
1	27.6467	27.1450	-----	No change in external appearance
2	27.5340	27.1388	0.023	Ditto
3	27.4439	27.1012	0.160	Ditto
4	27.4859	27.0570	0.280	Ditto
5	27.4623	27.0534	0.330	Indications of softening of bitumen
6	27.4592	27.0529	0.340	Increasing softening action, especially along edges of specimen.
7	27.4416	27.0525	0.341	Rail water, acting alone is not an active destructive agent, but does, in time, soften gradually the specimen, and decrease slightly the binding strength of the asphaltic cement.
	Total,		0.341	

Experiment 3.

Specimen - Bermudez asphalt top coat.

Agent - Water taken from gutter of street.

Deteriorations in Percentages of Original Weight of Specimens

Intervals Weeks	Weight-Grams		Deteriorations dry Wgt. Per cent	Observations.
	Saturated	Dried		
0	-------	27.5219	-----	Specimen solid and compact. Edges sharp.
1	27.9710	27.5219	-----	No change in external appearance.
2	27.9035	27.5206	0.040	Ditto
3	27.8450	27.4986	0.081	Noticeable decrease in weight and softening of specimen.
4	27.7068	27.4471	0.280	Slight pitting with increasing softness of specimen.
5	27.6210	27.4150	0.390	Same as preceding week.
6	27.7542	27.4036	0.400	Increasing pitting and softness of specimen. Decrease in weight not so great.
7	27.7235	27.3825	0.500	Street water seems to have the same effect on the street as NH_4OH due probably to manures in water. But the decrease in weight is very much less than in the preceding experiment with sewer water.
	Total,		0.500	

Experiment 4.

Specimen - Bermudez asphalt top coat.

Agent - Distilled water.

Deteriorations in Percentages of Original Weight of Specimens.

Intervals Weeks	Weight-Grams Saturated	Weight-Grams Dried	Deteriorations dry Wgt. Per Cent	Observations.
0	-------	26.9689	-----	Specimen solid and compact.
1	27.4575	26.9689	-----	No changes in external appearance.
2	27.3615	26.9656	0.012	Ditto
3	27.3219	26.9357	0.120	Ditto
4	27.2305	26.8700	0.360	Ditto
5	27.1492	26.8700	0.360	Ditto
6	27.3169	26.8700	0.360	Ditto
7	27.3026	26.8690	0.370	Distilled water has no effect upon the specimen at all.
	Total,		0.370	

Experiment 5.

Specimen - Bermudez asphalt wearing coat.

Agent - City water.

Deteriorations in Percentages of Original Weight of Specimens.

Intervals Weeks	Weight-Grams		Deteriorations dry Wgt. Per Cent	Observations.
	Saturated	Dried		
0	-------	27.1150	-----	Specimen solid and compact.
1	27.5432	27.1150	-----	No change in external appearance.
2	27.4800	27.1135	0.005	Ditto
3	27.4591	27.0462	0.250	Ditto
4	27.3325	26.9861	0.480	Ditto
5	27.3216	26.9821	0.490	No pitting of surface but a slight softening of the specimen.
6	27.3560	26.9806	0.490	No signs of pitting; the softening shows that continual contact of asphalt with water is to be avoided.
7	27.2196	26.9795	0.500	On the whole the action of city water is unnoticeable.
	Total,		0.500	

Experiment 6.

Specimen - Bermudez asphalt wearing coat.

Agent - NH_4OH (95 per cent solution)

Inter-vals Weeks	Weight-Grams		Deteri-orations dry Wgt. Per Cent	Observations.
	Satu-rated	Dried		
0	-------	26.7516	-----	Specimen in good condition. Solid and compact.
1	27.9120	26.4089	1.280	Noticeable decrease in weight but no external change.
2	26.7744	26.4054	1.280	Slight pitting of surface.
3	26.7550	26.3930	1.340	Pitting developing into a honey-combing effect.
4	26.6300	26.3805	1.390	Assumes a crumbling condition.
5	26.5940	26.3805	1.390	Same appearance as previous week. Asphalt seems to be losing its life and binding power.
6	26.5532	26.3800	1.390	Of all the deteriorating actions this is the worst. The specimen has become brittle, pitted through and through, and crumbling to the pressure of the finger.
7	26.5492	26.3798	1.490	
	Total,		1.490	

Experiment 7.

Specimen - Bermudez asphalt wearing coat.

Agent - Ammonia (NH_4OH) (50 per cent solution)

Deteriorations in Percentages of Original Weight of Specimens

Intervals Weeks	Weight-Grams		Deteriorations dry Wgt. Per Cent.	Observations
	Saturated	Dried		
0	-------	27.3180	-----	Specimen solid and compact.
1	28.0800	27.3175	0.002	No change in external appearance.
2	27.9944	27.3150	0.011	Slight pitting of external surface.
3	27.7999	27.1130	0.750	Quite a reduction of weight, pitting of surface much more evident.
4	27.4107	26.9833	1.220	Honey combing developing, the ammonia taking the dark tinge from the asphalt.
5	27.4096	26.9833	1.220	Ditto
6	27.3976	26.9815	1.230	Ditto
7	27.3955	26.9805	1.240	Although diluted to 50 per cent NH_4OH has very near same action as in previous experiment. Specimen pitted, soft to the touch, and brittle. Shows that the valuable property of the asphalt has been completely d destroyed.
	Total,		1.240	

Experiment 8.

Specimen - Bermudez asphalt wearing coat.

Agent - Ammonia (25 per cent solution).

Intervals Weeks	Weight-Grams		Deteriorations dry Wgt. Per cent	Observations.
	Saturated	Dried		
0	-------	26.6895	-----	Specimen solid and compact
1	27.3831	26.6863	0.001	No change in external appearance.
2	27.1830	26.6609	0.107	Ditto
3	26.9810	26.6509	0.107	Slight pitting of surface
4	26.9128	26.6331	0.210	NH_4OH acts in same manner as in preceding experiments honey-combing developes and specimen assumes a crumbling condition.
5	26.9078	26.6320	0.215	
6	26.9128	26.6135	0.280	By some peculiarity this specimen had as bad a deteriorated appearance as either the specimens in the two preceding experiments.
7	26.9023	26.6108	0.290	
&	Total,		0.290	

PLATE I.

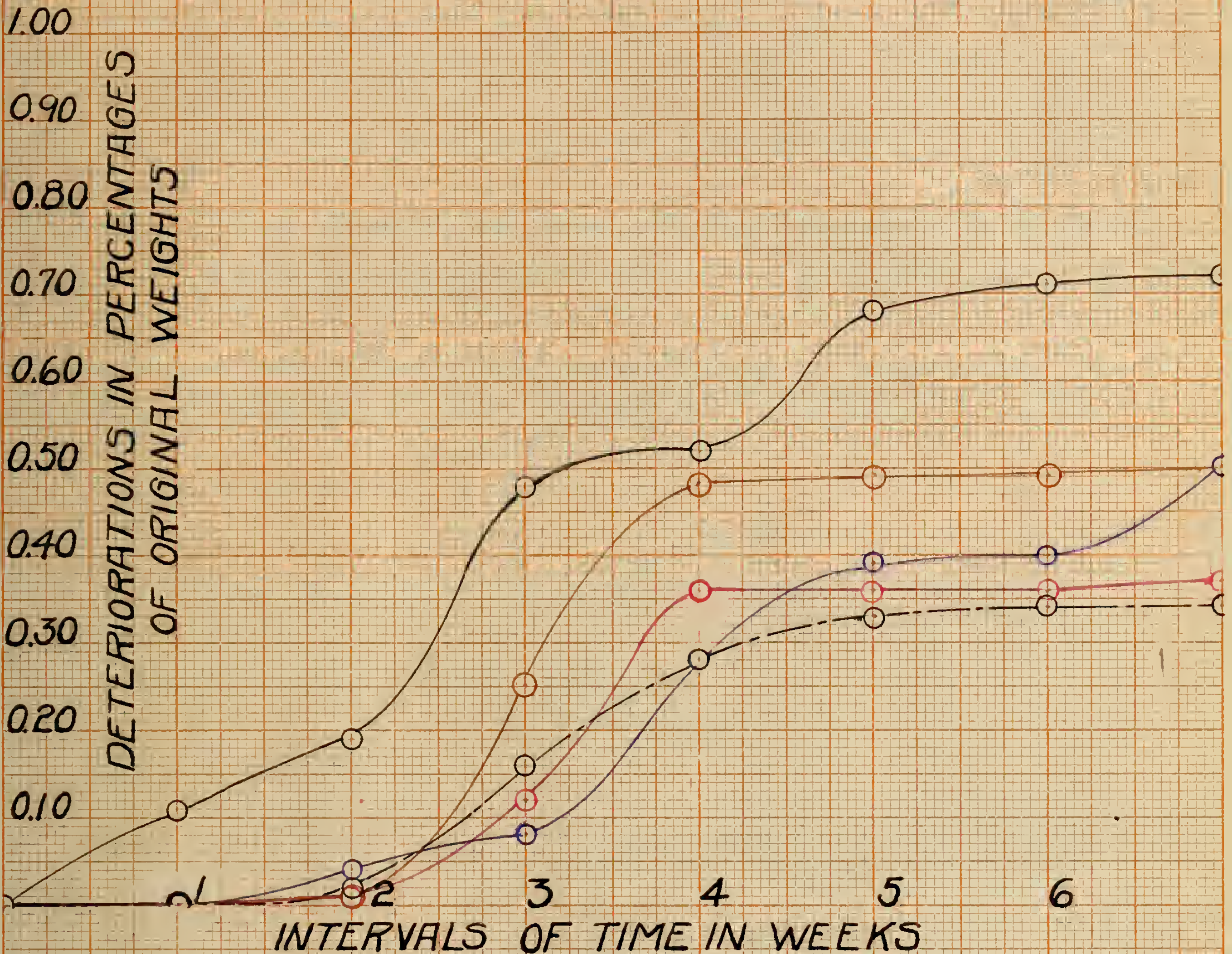


DIAGRAM OF DETERIORATIONS
IN AN
ASPHALT WEARING COAT MIXTURE

AGENTS:-

Sewer Water

Rain Water

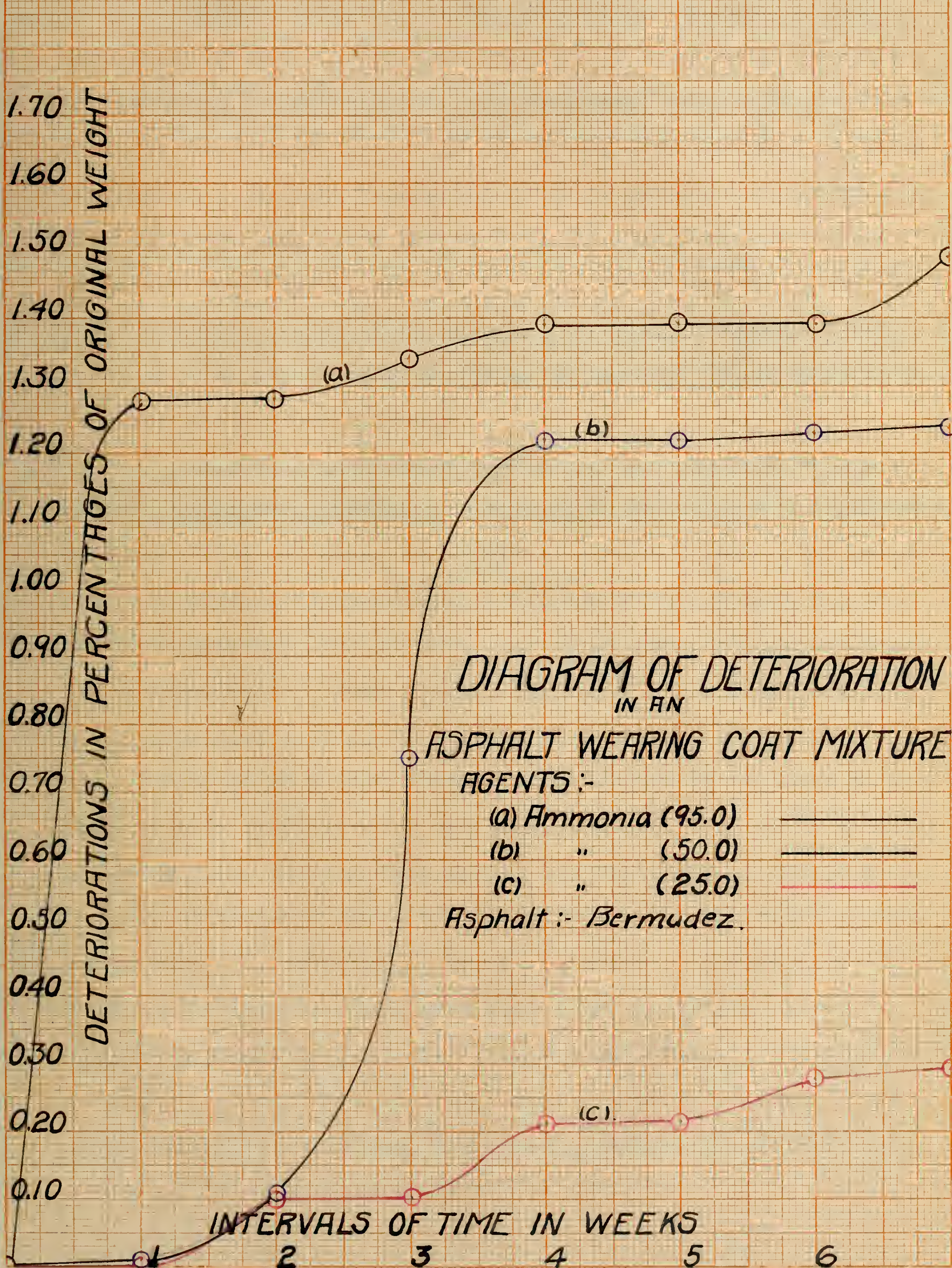
Street Water

Distilled Water

City Water

Asphalt:- Bermudez

PLATE 2.



1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
DETERIORATIONS IN PERCENTAGES OF ORIGINAL WEIGHT
(a)
(b)
(c).
DIAGRAM OF DETERIORATION
IN AN
ASPHALT WEARING COAT MIXTURE
AGENTS :-
(a) Ammonia (95.0)
(b) " (50.0)
(c) " (25.0)
Asphalt :- Bermudez.
INTERVALS OF TIME IN WEEKS
1
2
3
4
5
6
U. OF I. S. S. FORM 3

By the reduction in weight of each specimen in the experiments, it can be seen that everyone of the agents had some deteriorating affect varying from the slight action of distilled water to the violent action of the ninety-five per cent solution of ammonia. By some unobserved error or peculiar condition, the deterioration by the twenty-five per cent solution of ammonia was less than by any of the less active agents, although the appearance of the specimen gave very good evidence of deterioration. A better idea of the deteriorating action can be gotten from the plotted curves.

Although most deteriorating actions are due to organic agents, an asphalt surface is naturally more or less deteriorated by usage, like all other materials of construction. The amount which it suffers in this respect depends entirely upon the original workmanship, the traffic, and other local conditions which it is exposed to. Many asphalt pavements under light traffic have given good service for twenty-five years. However, a surface subjected to a very heavy traffic cannot be expected to remain in good condition for more than three to five years without minor repairs, varying from merely the smoothing of the wavy spot by heated hand tools to the tearing up of the wearing coat completely and replacing it by new material. The neglect of maintenance will in every case result in a complete failure of the pavement and additionally arouse much adverse criticism by citizens. This cause of failure can not be attributed to the character of the pavement, but more correctly to the narrow policy which is often pursued by public officers.

Elements of Cost.

The approximate cost of laying an asphalt pavement will be proportioned in percentages of the total cost about as follows:--

(a) Excavation and preparation of the earth road surface	7.0%
(b) Concrete base	38.0
(c) Binder, 1-1/2" thick.	14.0
(d) Asphalt top coat.	29.0
(e) Plant use	5.0
(f) Superintendency and miscellaneous expenses.	3.0
(g) Contingencies	4.0
Total.	100.0%

This table indicates that the greatest cost of any single part is centered in the construction of the concrete base and the preparation and laying of the top coat. In the construction of these two courses is also the greatest chance of error. In fact the efficiency of the courses governs to a great extent the amount of repairs which must be placed upon the pavement during its average life. An idea of the cost of maintaining an asphalt pavement may be gotten from table XVI, in which the cost of maintaining such in Washington, D. C., is given.

The plotted curve of the values in the last column shows that the greatest cost of repairs per square yard per year came on the twelfth, sixteenth, eighteenth and twenty-fourth years, and that repairs were extensively made about every five years.

Table XVI.

Cost of Maintaining Asphalt Pavements

of Various Ages at Washington, D. C.

Age in Years	Area Square Yards	Cost of Repairs for the year	Average cost per sq. yd. per year
5	1,841,435	11,897	0.0065
6	1,809,869	13,965	0.0077
7	1,747,461	31,385	0.0180
8	1,653,811	38,531	0.0233
9	1,597,313	42,871	0.0269
10	1,476,575	38,500	0.0260
11	1,292,200	43,003	0.0333
12	1,068,842	42,270	0.0396
13	913,795	31,546	0.0345
14	804,420	28.435	0.0354
15	698,826	21,576	0.0309
16	608,175	23,479	0.0386
17	560,823	18,913	0.0338
18	504,995	23,012	0.0456
19	374,800	11,951	0.0319
20	272,040	7,182	0.0264
21	192,643	3,879	0.0201
22	104,001	2,887	0.0280
23	36,332	678	0.0187
24	35,647	1,268	0.0356

Richardson's Modern Asphalt Pavements, p. 471.

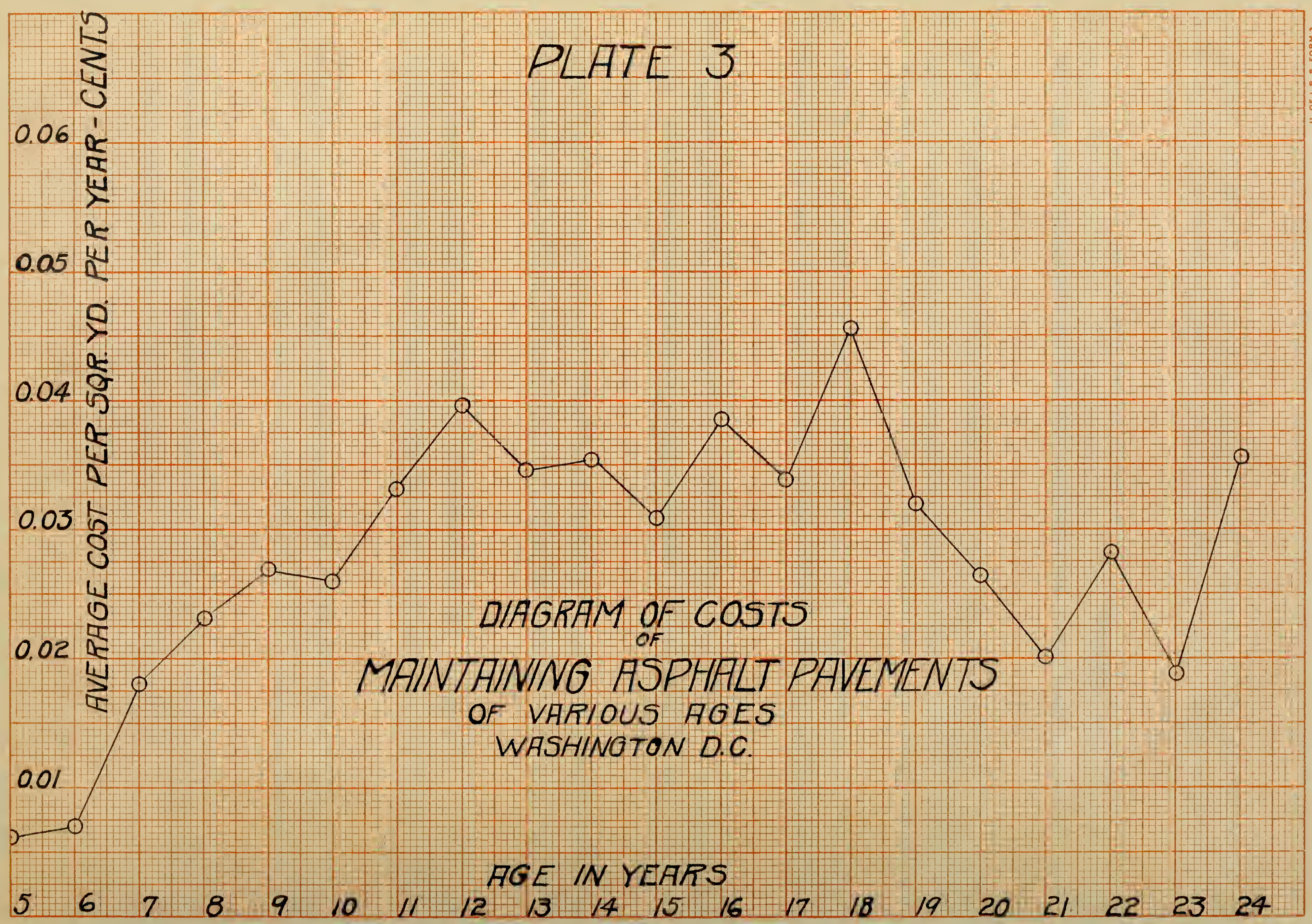


PLATE 3
AVERAGE COST PER SQR. YD. PER YEAR - CENTS
0.06
0.05
0.04
0.03
0.02
0.01
DIAGRAM OF COSTS
OF
MAINTAINING ASPHALT PAVEMENTS
OF VARIOUS AGES
WASHINGTON D.C.
AGE IN YEARS
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
U. OF I. S. S. FORM 3

Conclusion.

To summarize what has been said in this thesis concerning the defects and deteriorations occurring in asphalt pavements all failings can be attributed to the greatest extent to faults of construction:

(1) Due to improper specifications of the form of construction.

(2) Due to improper and careless construction.

(3) Due to improper maintenance, when the age is such that repairs are a necessity to prevent a rapid deterioration.

To secure the best construction of an asphalt pavement, the following factors must be observed:-

(1) There must be a well, sub-draibed and compacted base.

(2) There must be an intermediate monolithic material, preferably Portland cement concrete, to transmit the loads of traffic uniformly to the earth below.

(3) There must be an asphalt covering of a wearing capacity capable to meet all the traffic conditions and to resist the destructive agencies of extreme temperatures and other climate influences. The asphalt covering must be durable, must retain its smooth surface, must not be readily affected by water, and must be at all times hard and compact enough to meet all traffic requirements.